

Proposal to Enable a Neutral Mass Spectrometer and Wind Experiment on the Drag and Atmospheric Neutral Density Explorer (DANDE)

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Award Number: N00014-08-1-1137

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LONG-TERM GOALS

The objective of the DANDE mission is to provide an improved understanding of the satellite drag environment, including the effects of winds and densities, in low-Earth orbit.

OBJECTIVES

The Wind and Temperature Spectrometer (WTS) instrument for the DANDE satellite mission will be built and tested and separation actuators needed for the DANDE satellite will be purchased.

APPROACH

Several other observation satellites and missions have attempted to measure accelerations created by the atmosphere. However none have been able to differentiate between density accelerations and wind accelerations. Atmospheric density is the primary contributor to satellite orbit changes and decay. Differentiating between these two sources of accelerations is pivotal to understanding the atmospheric conditions and their affects on satellites.

The DANDE spacecraft will be able to observe wind velocity magnitudes from the in-track and cross-track directions. The observability of both density and wind speed is due to the fact that accelerometer measurements are proportional to the square of the velocity while mass spectrometer readings are proportional to the inverse of the velocity [1]. DANDE's onboard Neutral Mass Spectrometer will measure the energy and angular distribution of the incoming particles, enabling a determination of in-track and cross track winds.

Key Personnel:

Chris Koehler, Director, Colorado Space Grant Consortium, AFOSR UN5 PI/Advisor

Dr. Jeffrey Forbes, Glenn Murphy Professor, Department of Aerospace Engineering Sciences,
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Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 2009		2. REPORT TYPE		3. DATES COVERED 00-00-2009 to 00-00-2009	
4. TITLE AND SUBTITLE Proposal To Enable A Neutral Mass Spectrometer And Wind Experiment On The Drag And Atmospheric Neutral Density Explorer (DANDE)				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Colorado Boulder, Department of Engineering Sciences, Boulder, CO, 80309				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The primary research goals of the program are to (1) examine time-dependent oceanic radiance distribution in relation to dynamic surface boundary layer (SBL) processes; (2) construct a radiance-based SBL model; (3) validate the model with field observations; and (4) investigate the feasibility of inverting the model to yield SBL conditions. The goals of our team are to contribute innovative measurements, analyses and models of the sea surface roughness at length scales as small as a millimeter. This characterization includes microscale and whitecap breaking waves					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 9	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

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WORK COMPLETED

The requested funds were used to build and test the WTS instrument during summer and fall 2008 (actually two instruments, one test unit built during the summer and one flight unit built during fall). Utilizing technical drawings, students worked with Dr. Fred Herrero, NASA/GSFC, designer of WTS, to develop design modifications appropriate to DANDE. Students tested the DANDE WTS instrument at NASA Goddard in September 2008. All hardware was purchased and initial testing took place.

RESULTS

The NMS energy analyzer has been tested at NASA Goddard with the help of Dr. Fred Herrero and an example of this data is shown in Figure 1.

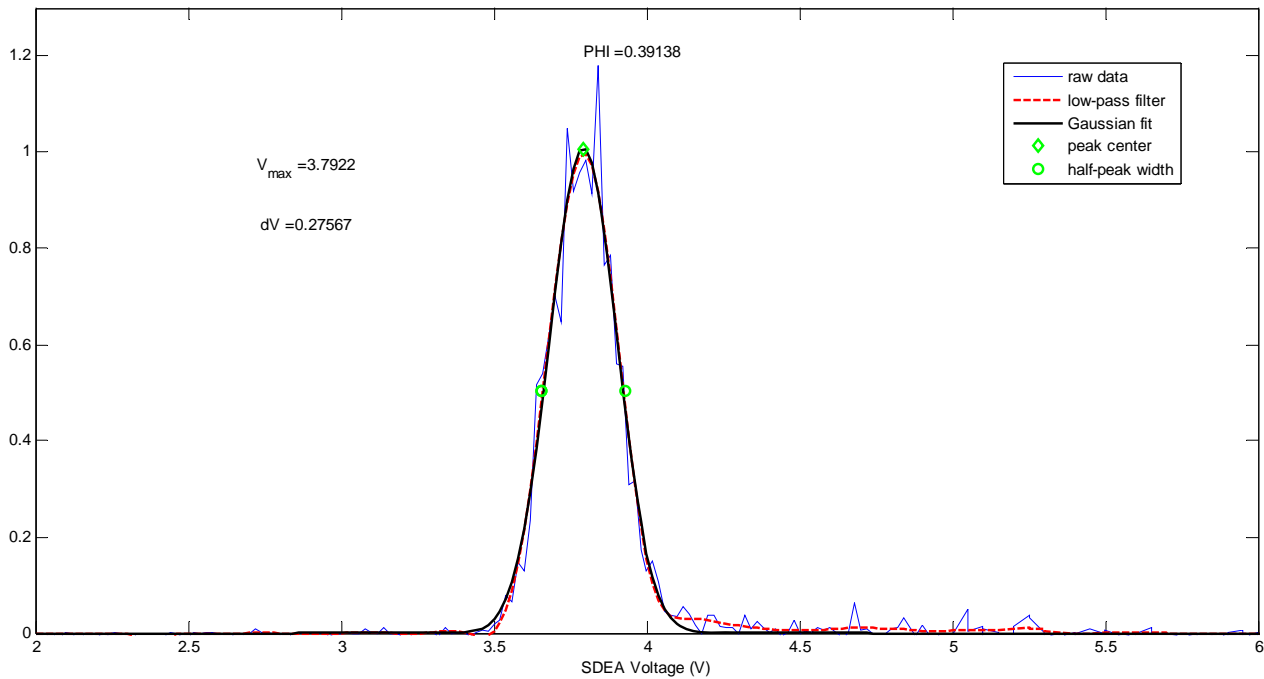


Figure 1: A mass spectrum collected by the DANDE NMS instrument.

The estimated precision of wind-speed measured by the NMS instrument is between 5 m/s and 10 m/s. The measured mass resolution is 10%. These measured values meet the science requirements of the DANDE mission. It has been determined that the NMS instrument is able to distinguish between oxygen and nitrogen.

IMPACT/APPLICATIONS

Neutral density measurements are obtained by first precisely characterizing the spacecraft's coefficient of drag, cross-sectional area, and mass. A near-spherical shape is optimal for maintaining a constant cross sectional area regardless of attitude and the coefficient of drag for spheres has been well studied during the first phase of the DANDE project [2]. Because of this, it is an ideal shape for reducing uncertainties. Furthermore, the spacecraft velocity must be known to around 0.01 km/s in order to recover density variations. This accuracy will be obtained from precise-orbit determination and high-task tracking provided by AFSPC/A9A. To relate the direction of the accelerometer axis to the velocity vector, the attitude of the spacecraft will be determined to approximately 3° of accuracy. The spacecraft will be spin-stabilized to the orbit-normal axis. In addition, the DANDE spacecraft will identify the wind induced acceleration from that induced by density fluctuations by flying a mass spectrometer capable of measuring the wind speed and direction. Finally, the spacecraft will measure the acceleration to a precision of 10 nano-g or better in the direction of the velocity vector. According to error analysis, these accuracies will allow DANDE to recover 2% to 3% density fluctuations in the amplitude of the day-night density variation cycle at solar maximum (2009-2012). The mass-spectrometer on the DANDE spacecraft will also be used to analyze atmospheric composition. Specifically, molecular nitrogen and atomic oxygen levels will be measured to infer additional density data, adjust the coefficient of drag accordingly, and provide additional science. This combination of instrument data has never been flown in orbit before and can shed light on some properties of our neutral atmosphere which are not yet understood or poorly characterized ultimately leading to improved models and better orbit determination.

The Air Force HASDM operation makes use of a set of approximately 80 satellites at various altitudes to obtain near-real time updates for a calibrated global density model. While the in-situ measurements described above will lead to model validation and improvement, radar tracking data will be able to provide average density values once to several times each day. This data is especially important for HASDM at lower altitudes where the DANDE satellite will be deployed. The spherical nature of the sphere allows for even better density determination as the attitude does not introduce uncertainties into the density measurements by varying the effective cross sectional area or the coefficient of drag. Although Space Command is unable to provide the Colorado team with the raw tracking data, it has been agreed that processed density and orbit information from high-priority tracking will be disseminated along with the fitted drag coefficient. The Colorado team will be able to use this information to evaluate calibration and data assimilation techniques and to complement the in-situ data. In addition to HASDM the team will also evaluate the new HWM07 Horizontal Wind Model.

RELATED PROJECTS

DANDE (dande.colorado.edu) is a 50 kg, spherical spacecraft 50 cm-diameter spacecraft being developed at the Colorado Space Grant Consortium in conjunction with the Aerospace Engineering Sciences department at the University of Colorado, Boulder. The spacecraft is designed to carry a complement of accelerometers for the measurement of drag, and a Wind and Temperature Spectrometer (WTS) to measure winds and neutral composition. Radar tracking will be used in conjunction with the in-situ drag data to obtain coefficient of drag measurements between 350 and 100 km. The mission objectives include validating and improving density and wind models, and better understanding quantitatively the degree to which knowledge of neutral winds is necessary for accurate satellite drag predictions. University of Colorado graduate and undergraduate students are designing and integrating the spacecraft to be delivered for environmental testing by summer of 2010. ANDE (<http://web.usna.navy.mil/~bruninga/ande.html>) is also a 50-cm spherical spacecraft designed to measure drag and densities with a WTS-type instrument as well as laser and radar ranging. This spacecraft is being developed at the Naval Research Laboratory in conjunction with the U.S. Naval Academy. ANDE will be able to measure cross-track winds using the WTS similar to that on DANDE, and will also provide good coefficient of drag estimates because of its spherical shape. Both ANDE and DANDE are nominally scheduled for flight around the next solar maximum (2009- 2010). Both spacecraft are designed for about a year of operations. The major differences between the spacecraft include attitude stabilization and power. ANDE is a tumbling spacecraft while DANDE is spin stabilized. DANDE will also be covered with photovoltaic cells because of the larger amount of sensors and longer duty cycles as well as Nanosat imposed launch vehicle safety requirements. Due to its solar cells, DANDE is likely to deviate more from a perfect spherical shape than ANDE. ANDE is set to fly in a low- inclination orbit while the nominal DANDE orbit will be near-polar. Because of this and the complementary data sets each program provides, the development of density models and study of the drag environment would benefit tremendously from flying both ANDE and DANDE during the same time frame.

The ANDE and DANDE missions are highly synergistic with the recent MURI award to the University of Colorado entitled “Neutral Atmosphere Density Interdisciplinary Research (NADIR)”. The objective of NADIR is to significantly advance understanding of drag forces on satellites, including density, winds, and factors affecting the drag coefficient. A level of understanding that will enable specification and prediction at the “next level” of performance is sought under this program. The

specific goals are to: (1) Understand the physical processes driving the variability of neutral atmospheric density; (2) Determine the relationship between neutral density *structure* and satellite drag; (3) Improve forecasts of the drivers of the system including wave activity from the middle and lower atmosphere, geomagnetic/magnetospheric forcing, and solar EUV; (4) Provide the information to improve empirical models of neutral density; (5) Determine the most valuable dataset required to specify and forecast the system state; and (6) Improve estimates of drag in the re-entry regime (100-200 km). Thus DANDE, ANDE and NADIR all focus on atmospheric density and satellite drag variability with a view towards improving predictive capabilities. This collective serendipity provides us with a unique opportunity to significantly advance our knowledge.

REFERENCES

1. Moe et. al., “Method for Deriving Densities and In-Track Winds During Storms”, AIAA-2006-6396, 2006
2. Pilinski, Marcin, “*Analysis of a Novel Approach for Determining Atmospheric Density from Satellite Drag*”, M.S. Thesis, University of Colorado, Boulder, 2008

HONORS/AWARDS/PRIZES

Marcin Pilinski, University of Colorado, 1st Prize, Student paper Competition, 2009 Conference on Small Satellites, “An Innovative Method for Measuring Drag on Small Satellites”, AIAA/Utah State University.